The Design and Performance Reliability of Computers
and Their Air Force Applications

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I. INTRODUCTION

This report summarizes the results of a two-year research program undertaken to investigate aspects of reliability of computer systems particularly with regard to theoretical aspects of their design and performance in Air Force applications. Most of the work described was performed by students under the direction of Professors A. Klinger, D. Martin, and J. Vidal, and documented in Master's and Doctoral theses. Major portions of the work were concerned with theoretical studies of image processing, pattern recognition, and computer models of unknown systems (identification). However, some studies investigated design of reliable logical hardware, computer software, and multiprocessor resource allocation modes.

The report consists of this introduction, a general description of the research, a detailed section on the specific research topics and results, and sections on conclusions and further work, student support, and publications.

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13. ABSTRACT

This report summarizes the results of a two-year research program undertaken to investigate aspects of reliability of computer systems particularly with regard to theoretical aspects of their design and performance in Air Force applications. Most of the work described was performed by students under the direction of Professors A. Klinger, D. Martin, and J. Vidal, and documented in Master's and Doctoral theses. Major portions of the work were concerned with theoretical studies of image processing, pattern recognition, and computer models of unknown systems (identification). However, some studies investigated design of reliable logical hardware, computer software, and multiprocessor resource allocation modes.

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II. RESEARCH DESCRIPTION

Three types of research were conducted:

1) pattern recognition, image processing, and system identification

2) software systems and logic design, and

3) models of reliability and performance.

In the first category, two important classes of Air Force applications were defined: continuous time signal data and pictorial data. Research was conducted on improving methods for representing data from both classes for computer processing. Continuous signal data arises in radar, communications, and surveillance by sensors as well as in analog and hybrid simulation. Pictorial data is obtained by photo-optical means in Air Force reconnaissance missions. Specific problems often yield insight into general characteristics of these classes of data. Hence research was conducted in areas sometimes ranging to diverse applications such as biomedical image processing. General properties discerned from this research were developed and presented in other publications. Commonalities to objectives such as search and storage of visual scenes were found so that the research enhanced the central goal of the project. The subjects of pattern recognition and system identification are discussed in greater detail in Section III, Specific Research Topics and Results.

The second category began with an intensive effort to introduce redundancy in digital logic design in a way that would best improve overall system reliability (lower probability of failure). A similar software effort was conducted to examine deadlocks in a parallel processing system. The former effort examined introduction of optimal redundant allocations of logic

elements while the latter involved a comparison of simulation model results with actual measurements on a large computer.

A probability-model theoretical investigation of memory space and central processor time allocations and their effect on "failure" measures such as page faulting concludes the research conducted here. This effort is related to the second category but deserves its own descriptive heading under models of reliability and performance.

A common aspect of all the research conducted was the use of statistical models. Likewise, the computer systems which were modeled were found to require additional interactive processing in order to further the research objectives. This was reflected first in the proposal which resulted in the new AFOSR Grant 72-2384, and the development of a set of hardware criteria which led to the purchase of IMLAC equipment which has been installed in a laboratory facility jointly used by Professors J. Vidal, W. Karplus, and A. Klinger and their research students. (The purchase was partially supported by AFOSR 70-1915 and partially by NSF GJ 32221.)

III. SPECIFIC RESEARCH TOPICS AND RESULTS

The overall objective of the research program was to isolate ways in which design and performance reliability of Air Force computers could be improved. At the commencement of the project it was believed that a combination of new optimization methods with probabilistic properties of redundancy (introduction of additional logic elements) could introduce design reliability improvements. It was also believed that several performance objectives could be improved by adapting pattern recognition theory to applications and by utilizing piecewise continuous probability laws in modeling actual failure rates. In all these cases the theoretical capability existed and the need was for adapting that theory to computer realities through creation of software - i.e., computer programs. This goal of program development sought to create working tools for testing the theoretical concepts applicability to the contemporary needs in the areas of reliability of computers which we investigated, namely

1) pattern recognition, image processing, and system identification,
2) software systems and logic design, and
3) models of reliability and performance.

In actuality, program development accomplishments were constrained by a combination of computer hardware limitations. Nevertheless applied and theoretical advances were made in all three areas. Emphasis was placed on use of the UCLA campus computing large computer (IBM 360/91) and small computers already in the Computer Science Department laboratories, in particular an XDS 920 computer. Both systems were used advantageously, the first on all three areas, and the second in image processing applications.

The work on pattern recognition, image processing, and system identification consisted of several different activities united by the goal of finding ways to better use computers in applied contexts. A general principle in pattern recognition is the description of data by features. A. Klinger, A. Kochman and N. Alexandridis[2] developed an hierarchical method for defining features to correspond to the current decision-level for chromosome slide pictures. The principles are applicable to any two-dimensional image data. This work was complemented by analyses done by A. Klinger and H. Sugiyama re sequential accumulation of radioisotope scanning information[3] which were simulated by I. Rynell in her M.S. thesis research. Some preliminary results of that work were published in a paper by I. Rynell and A. Klinger[6]. The general concept of defining features or intensively scanning high interest areas in an image, according to the kind of decision that the computer must make is a practical way to view the problem of pictorial pattern recognition.

A parallel activity involved introducing these concepts into general planning and decision-making contexts. At an applied level, S. Ramadorai and T. Lineck each used these sequential decision concepts in M.S. thesis research involving radar data processing. N. Chin introduced a set of software processing functions for one-dimensional (e.g. continuous time) signals which extracted the presence of significant features in the data, as part of his M.S. thesis research. A. Klinger presented these aspects of sequential search in medical pattern recognition problems at the Joint National Conference on Major Systems[10] and extended the sequential search and feature extraction concepts to the theoretical planning and decision-making level in a published paper[5] (E. Purcell aided in the construction of a table which appears there).

An important aspect of feature extraction is the basis or domain of representation of the signal. In an early paper[1] A. Klinger suggested a difference-differential equation/generating function approach to representation of solutions to partial differential equations. Later, the representation of qualitative phonomena seemed to be critical. Hence the research investigated notions of boundary shape: a publication[4] and a presentation[9] to the Joint National Conference on Major Systems by A. Klinger were related to this question.

At the same time N. Alexandridis was conducting doctoral research regarding image processing which led to a Ph.D. thesis, several publications, and a patent application. The work done here involved aspects of feature extraction and pattern recognition as the publication by N. Alexandridis and A.Klinger[7] and by N. Alexandridis[15] indicate. Several of the main contributions of that thesis concern representation of one and two-dimensional patterns with respect to the Rademacher-Walsh functions, a complete orthonormal basis (the approach in[1] suggested a nonorthogonal, easily computed set). The patent application concerns the possibility of building hardware devices to facilitate obtaining a Walsh-Hadamard transformation of a two-dimensional picture in real-time - i.e., a representation of the picture in an expansion with respect to two-dimensional Rademacher-Walsh functions. Some aspects of this were discussed in the paper published by N. Alexandridis and A. Klinger[8] while the basic theoretical interconnections between the natural Walsh-Hadamard Fourier series representation order and the pattern axis-symmetry order were published[15] by N. Alexandridis. That image processing research is closely related to pattern recognition/feature extraction is suggested by the Masters degree work done by P. Topping who created software for image scanning which localized the scan

in zones of high interest: a partial implementation of the picture data structure suggested in the theoretical pattern search paper[5] by A. Klinger. Further discussion which indicates how the partial or localized scan can be used prior to Walsh-Hadamard transformation to yield improved transmission of informative parts of a visual scene will be found in the next section.

System identification research requires knowledge of the number of independent modes or phenomena in a signal. J. Vidal supervised doctoral research by D. Schwartzmann which addressed the topic of intrinsic dimensionality. This relates to how many terms in a Fourier expansion or how many features are needed to adequately model an unknown system. J. Vidal and D. Schwartzmann published a paper[13] describing their use of clustering considerations to resolve topologically related data. D. Schwartzmann (like N. Alexandridis) completed his Ph.D. work and received the degree.

Parallel applied efforts in system modeling and pattern recognition were part of the research. These include a Master's thesis by K. Doane on speech recognition and Ph.D. research by S. Saib on speech recognition, in the realm of continuous signal processing. W. Meyers completed a M.S. thesis on credit card verification by computerized-fingerprint matching. D. Zweiban created computer programs for chromosome scene processing, computer interfacing, and interactive signal processing, as well as an M.S. research project on learning automata and patterns. A. Klinger was consulted on drug treatment data pattern analysis by J. Satterfield and they published a paper[12] together. A. Klinger organized a Workshop on Decision-Analysis at the Joint National Conference on Major Systems[11] which dealt with related questions of pattern and decision analysis for qualitative problems. M. Hee completed her M.S. project on a decision-analysis problem.

Work on software systems and logic design was most prominent in the initial stages of the grant research. M. Tam created interactive design programs for introducing redundancy in a digital logic net to optimally increase probability of success (of some path functioning to implement a given logic expression). He did not complete this research, however, and he is now employed in industry. D. Martin published a paper on Boolean matrix computations of precedence[14]. In addition, he supervised the Masters degree research of S. Mrithunjayan whose thesis concerned a key software system problem in parallel processing, that of deadlock. Mrithunjayan simulated operation of the 360/91 system at UCLA and compared his results to measured data. J. Rao has been advanced to candidacy for the Ph.D. on the basis of his research on the two-resource allocation problem in parallel processing (computer memory and processor time): he has been working with A. Klinger and is expected to complete his thesis in 1972. D. Hibbits and F. Kamoun have been working on software with J. Vidal.

Work on models of reliability and performance include aspects of the above-mentioned research by Mrithunjayan and Rao. In addition J. Rao published a note[17] on hazard rate functions. Likewise major reliability and performance research was included in the M.S. thesis by I. Rynell, which introduced new likelihood ratio decision rules, that by S. Ramadorai, which calculated in detail probability of detection for different radar digital-window sizes and threshold-detection algorithms, that by T. Lineck, and the paper[5] by A. Klinger which discussed reliable search.

IV. CONCLUSIONS AND FURTHER WORK

The overall two-year research program fulfilled its primary objectives. A number of areas were found where existing theory could be applied to computer design and performance reliability problems, and aspects of existing theory were isolated which need extension to enable practical use of computer power in operational contexts. At the same time a substantial number of graduate students received valuable training and experience. One student remarked that the project he pursued gave him his first experience with a Hands-on digital computer. Several undergraduate students received support for programming and research assistance. One, A. Kochman (now a computer programming consultant), coauthored a paper[2] and made a presentation at a national conference. Limitations on existing computer hardware at UCLA and increased emphasis on interactive computation and display led to the decision to seek added equipment.

Plans for future research include applying the equipment which is now installed (an IMLAC Programmable Display System) in several modes. One goal is to direct a picture scan to areas of high information content so that transformation (e.g. FFT or Fast Fourier Transformation, Walsh-Hadamard, etc.) and transmission or storage of the result, can be performed in great detail where there is important data and in less detail where there is none. I.e., more terms would be retained in the truncation of the infinite series obtained from transformation where there is pictorial information content, less terms retained where there is none, yet the total amount of Fourier coefficient data obtained, stored, and transmitted would be the same as in standard picture processing techniques.

The work has experienced a general shift toward pattern recognition, decision analysis, and statistical approaches to planning. This will involve extensions in the areas of pattern search, hierarchical decisions, and qualitative data. Subjective measures, statistics of rank order data, and multilevel weighting and data incorporation are all topics which need to be explored. Man-machine interaction via visual displays and graphic input will be needed in future investigations.

V. STUDENT SUPPORT

Doctoral Students:

1. N. Alexandridis, Ph.D. dissertation, "Walsh-Hadamard Transformation in Image Processing," completed in 1971. Published as UCLA Engineering Report No. 71-08, (portions published as "The Hadamard Transform in Image Processing and Pattern Recognition," UCLA Engineering Report No. 70-11, 1971). Currently with Ultrasystems, Newport Beach, California.
2. J. Rao, Ph.D. dissertation, "Analytic Models for Allocation of Computer Memory and Processor Time," to be completed in 1972. Currently Post Graduate Research Engineer at UCLA.
3. D. Schwartzmann, Ph.D. dissertation, "Black Box System Identification via the Topological Dimensionality Approach with Applications to Neurophysiological Problems," completed in 1972. Currently Post Graduate Research Engineer at UCLA.
4. M. Tam, did not complete doctoral dissertation research.

Master's Students:

1. M. Hee
2. D. Hibbits
3. F. Kamoun
4. W. Meyers
5. S. Mrithunjayan
6. E. Purcell
7. S. Ramadorai
8. I. Rynell
9. D. Zweiban

Undergraduate Assistants:

1. M. Alperin
2. A. Kochman
3. G. Roy
4. D. Sekiguchi
5. C. Smith

Master's Students Degree Research:

1. N. Chin, "A Proposed Method for Statistical Feature Extraction of One Dimensional Signals," M.S.
2. K. Doane, "An Approach to Computer Speech Recognition: The GCM Wave Function Analysis System," M.S.
3. M. Hee "Mischenko's Pursuit Problem," M.S.
4. T. Lineck, "Stopping Rule Theory: An Application to the Radar Search Problem," M.S.
5. W. Meyers, "A Credit Card Verification System," M.S.
6. S. Mrithunjayan, "Simulation and Measurements of Deadlocks in a Parallel Processing System," M.S.
7. S. Ramadorai, "Pattern Recognition and Reliability of Detection in Digital Radar Processors," M.S.
8. I. Ryncll, "Random Simulations and Statistical Tests for Pattern Recognition; Application to Scanning for Detection of Tumors in Nuclear Medicine," M.S.
9. P. Topping, "Data Structures for Image Scanning," M.S.
10. D. Zweiban, "Reproductive Learning Algorithms for Cellular Automata in Pattern Recognition," M.S.

VI. PUBLICATIONS

1. "Generating Functions, Difference-Differential and Partial Differential Equations," IEEE Transactions on Education, Vol. E-13, No. 1, pp. 46-48, July 1970.

2. "Computer Analysis of Chromosome Patterns: Feature Encoding for Flexible Decision Making," Klinger, A., Kochman, A., and Alexandridis, N., presented at the Symposium on Feature Extraction and Selection, Argonne National Laboratory, October 1970. IEEE Transactions on Computers, Special Issue on Feature Extraction and Selection in Pattern Recognition, C-20:1014-1022, September 1971.

3. "Computer-Aided Scanning," Klinger, A. and Sugiyama, H., presented to International Federation of Automatic Control Symposium, Kyoto, Japan, August 1970. Preprints of papers for IFAC Kyoto Symposium on Systems Engineering Approach to Computer Control, August 1970, pp. 615-618.

4. "Pattern Width at a Given Angle," Communications of the ACM, Vol. 14, No. 1, pp. 15-20, January 1971.

5. "Patterns and Search Statistics," Symposium on Optimizing Methods in Statistics, Ohio State University, Columbus, Ohio, June 14-16, 1971, Optimizing Methods in Statistics, ed. by J. Rustagi, Academic Press, New York, 1972.

6. "Simulation Research on Some Effective Scanning Strategies for Tumor Detection," I. Rynell and A. Klinger, Proceedings of the Tokyo AICA Symposium on Simulation of Complex Systems, H-3/1-H-3/9, September 1971.

7. "Walsh Orthogonal Functions in Geometrical Feature Extraction," N. Alexandridis and A. Klinger, Proceedings of the 1971 Symposium on Applications of Walsh Functions, IEEE Transactions on Electromagnetic Compatibility, EMC-13:18-25, August 1971.

8. "Real-Time Walsh-Hadamard Transformation," N. Alexandridis and A. Klinger, IEEE Transactions on Computers, C-21:288-292, March 1972.

9. Abstract, "Quantitative Measures, Computing, and Qualitative Problems," Decision Analysis Workshop, Joint National Conference on Major Systems, October 1971, Anaheim, IEEE Transactions on Systems, Man, and Cybernetics, SMC-2:274-275, April 1972.

10. Abstract, "Search and Biomedical Pattern Recognition," Pattern Recognition Workshop, Joint National Conference on Major Systems, October 1971, Anaheim, IEEE Transactions on Systems, Man, and Cybernetics, 1972.

11. 1971 Workshop on Decision Analysis (Report) IEEE Transactions on Systems, Man, and Cybernetics, pp. 274, April 1972.

12. "Stimulent Drug Treatment of Hyperkinetic Children: Data Analysis," A. Klinger and J. Satterfield, Proceedings of the Fifth Hawaii International Conference on System Sciences, Supplement Computers in Biomedicine, pp. 166-169, January 1972.

13. "Intrinsic Dimensionality Considerations in Active "Black Box" System Identification," J. Vidal and D. Schwartzmann, Proceedings of the Fifth Hawaii International Conference on System Sciences, pp. 255-257, 1972.

14. "A Boolean Matrix Method for the Computation of Linear Precedence Functions," D. Martin, Communications of the ACM, 15:448-454, June 1972.

15. "The Hadamard Transform in Template Matching Pattern Recognition," N. Alexandridis, Proceedings of the Third Hawaii International Conference on System Sciences, pp. 127-130, January 1970.

16. "Relations Among Sequency, Axis Symmetry, and Period of Walsh Functions," N. Alexandridis, IEEE Transactions on Information Theory, IT-17, 4:495-497, July 1971.

17. "Some New Proofs of Results on Hazard Rate Functions," J. Rao, IEEE Transactions on Reliability, TR-16, August 1971.